CHAPTER 1

FUNDAMENTALS OF DATA COMMUNICATIONS

INTRODUCTION

Although you, as a Fire Controlman, may not be directly involved in data communications, you definitely need to be aware of how data communications affects your ship's mission. This training manual introduces and explains the basics of data communications. Computer data frequently must be transmitted from one point to another. The distance involved maybe a few feet, or it may be hundreds of miles. Data transited over long distances often must be converted to a form compatible with either landline or radio wave transmission and reception. This chapter explains how such conversion occurs and techniques used in the conversion and transmission procedures.

After completing this chapter, you should be able to:

- **State the types of communications systems.**
- **Describe the decibel system of power measurement.**
- **Explain asynchronous and synchronous communications as used in data communications systems.**
- **Describe the methods of data modulation and demodulation used in various types of data networks.**
- **Describe the operation of modems used in data communications networks.**
- **Describe the methods of multiplexing data in communications networks.**

COMMUNICATIONS SYSTEMS

The devices used to transfer digital data makeup what is known as a communications system. In its most basic form, a communications system consists of the three components shown in figure 1-1. They are the transmitter, the receiver, and a communications channel that connects the two units.

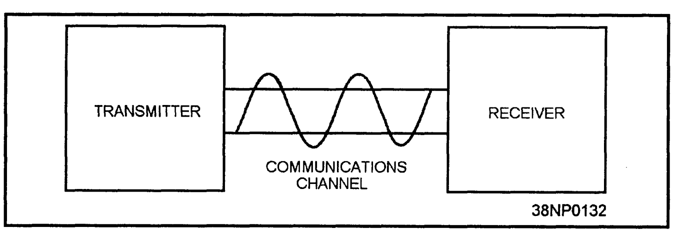

Figure 1-1.—Communications system.

The transmitting equipment converts the data of the sending system into a form that can be sent over the communications channel, accepted by the receiving equipment, and converted back into usable data by the receiving system. Data sent over a communications system is in one of the following two forms: analog or digital.

An analog signal used in data communications varies continuously between a minimum and a maximum value. As the signal varies, it assumes an infinite number of specific values between the two limits. The signal can be varied in amplitude (amplitude modulation), frequency (frequency modulation), or phase (phase modulation) to convey the data. We will discuss each type of modulation later in this chapter.

A digital signal has a limited set of values (1 or 0, true or false, etc.). A limited number of discrete pulses can be transmitted in a fixed period. The unique sequence of the bits represents the data.

Digital equipments (computers and peripherals) within a system normally communicate with each other in pure digital pulses (serial and parallel). Transmitting digital information over a distance requires the use of special equipment to convert digital data pulses into a form acceptable to the various types of communications channels. The equipment most often transmits digital data over a distance by varying a continuous analog signal in amplitude, frequency, or phase.

Communications channels that can pass data in two directions (transmit and receive) are known as **duplex channels.** Single-direction channels are **simplex channels.** Duplex channels may operate in one of the following two modes: half-duplex or fill-duplex. Half-duplex channels transmit data in one direction, pause, and then receive data coming from the opposite direction. Full-duplex channels, on the other hand, can transmit and receive data simultaneously.

TYPES OF COMMUNICATIONS CHANNELS (TRANSMISSION MEDIA)

In the fleet and at shore activities, you will encounter several forms of communications channels. The most common channels are landlines and radio communications.

Landlines

Landlines are physical lines or cables that connect the digital equipment. Originally, landlines referred to telephone lines and were limited to carrying analog audio frequencies (voice frequencies). For digital information to be carried over these lines, the characteristics of one or more tones or carriers in the audio-frequency range had to be modified in amplitude, frequency, or phase.

Today, telephone lines are commonly used in many network applications. Bulletin boards, such as BUPERS ACCESS, use existing telephone lines; but many landline-based systems use dedicated lines. Dedicated lines are common in local area networks (LANs). In a LAN system, several computers are joined together to share information with all the users on the system. System connections are made using coaxial, dual-coaxial, fiber-optic, or twisted-pair cable. The type of cable depends on several factors, such as the number of users on the LAN and the maximum distance between workstations.

The device used to convert the digital data into a form usable by the communications channel and back to digital data is known as a **modem.**

Modem is an acronym for MOdulator Demodulator. The modulator function converts the data of the transmitting system into discrete modifications of the tone or carrier signals. The demodulator converts the data-carrying tone or carrier signal into digital data for the receiving system.

Radio

Radio waves have been used for teletype and voice communications for many decades. The advantages of radio-based systems are that they are more mobile and can communicate over barriers such as large bodies of water. Tactical information links, like those we will cover in chapter 2, are almost exclusively radio-based.

Radio communications are based on frequency ranges or **radio-frequency bands.** The frequency range of the **carrier frequency** determines the operational characteristics of the system. Table 1-1 illustrates the international frequency bands and their uses. The tactical digital information systems used by the Navy generally use portions of the **hf** and **uhf** bands.

Table 1-1.—Frequency Bands and Their Applications

FREQUENCY	DESCRIPTION	APPLICATION
Up to 300 Hz	Extremely low frequency (elf)	Special communications
300 Hz – 3 kHz	Voice frequency	
3 KHz – 30 kHz	Very low frequency (vlf)	Shore-based communications, experimental
30 KHz – 300 kHz	Low frequency (lf)	Shore-based communications, navigation
300 KHz – 3 MHz	Medium frequency (mf)	Commercial broadcast band (550 kHz to 1700 kHz), communications on either side of the broadcast band
3 MHz – 30 MHz	High frequency (hf)	Ship and shore long-range communications
30 MHz – 300 MHz	Very high frequency (vhf)	Communications, navigation
300 MHZ – 3 GHz	Ultra high frequency (uhf)	Line-of-sight communications to 400 MHz; above this frequency, radar and special equipments
3 GHz – 30 GHz	Superhigh frequency (shf)	Radar and special equipments
30 GHz – 300 GHz	Extremely high frequency (ehf)	Radar and special equipments

In the radio transmitter, the data signals (discrete or tones) are modulated (impressed) on to the carrier frequency and transmitted into space when the transmitter is keyed. A receiver tuned to the carrier frequency picks up the signal and demodulates the data-carrying signals from the carrier. The data signals can then be converted to digital data by the appropriate devices. For more information on radio operations, refer to Navy Electricity and Electronics Training Series (NEETS), Module 17— *Radio-Frequency Communications Principles.*

THE DECIBEL MEASUREMENT SYSTEM

Technicians who deal with communications equipment often speak of the gain of an amplifier or a system in units called decibels (dB). Decibels are used as an indication of equipment performance; therefore, you need a basic understanding of the decibel system of measurement.

As the actual calculation of decibel measurement is seldom required in practical applications, the explanation presented in this text is somewhat simplified. Most modern test equipment is designed to measure and indicate decibels directly. This design eliminates the need for complicated mathematical calculations. Nevertheless, because many data link system alignment procedures center around dB readings and references, you need to understand the significance of an equipment gain rating as expressed in decibels.

The equipment used in communications systems consists of several components, such as amplifiers, communications lines, antennas, couplers, and switches. Each component in the system will affect the signal by introducing a signal loss or gain. These losses and gains can be described by a ratio of the power input and output by the equipment or cable. The ratio can be calculated by using the following formula:

$$\frac{\text{Output power}}{\text{Input power}} = \text{Power ratio}$$

If a communications system has four components, the gain or loss at each component must be calculated and these ratios multiplied. The following is an example of the gain/loss calculation of a four-component system:

$$\frac{1}{2} x \frac{1}{10} x \frac{1}{25} x \frac{1000}{1} = 2$$

In this system, the output of the signal is twice as strong as the input to the system.

As you can see, this constant multiplication of the ratios can be wearisome, and the products can be extremely small or large. Therefore, the discovery that adding the logarithms of the numbers would yield the same result as this calculation led early scientists to develop the unit of measure called the *bel.*

The bel, named in honor of Alexander Graham Bell, expresses the logarithmic ratio between the input and output of any given component, circuit, or system. The bel maybe expressed in voltage, current, sound levels, or power. The formula is as follows:

$$N = \log_{10} \frac{P1}{P2}\ bel$$

The gain of an amplifier can be expressed in bels (N) by dividing the output (P1) by the input (P2) and taking the base 10 logarithm ($\log_{10}$) of the resulting quotient. Thus, if an amplifier doubles the power, the quotient will be 2. When you consult a logarithm table, you will find that the base 10 logarithm of 2 is 0.3; so the power gain of the amplifier is 0.3 bel.

Experience has shown that the bel is a rather large unit that is difficult to apply. A more practical, easier unit to apply is the decibel (1/10 bel). Any figure expressed in bels can be converted to decibels by multiplying the value by 10. Thus the ratio of 0.3 bel is equal to 3 decibels.

The reason the decibel system is used to express signal strength is shown in table 1-2. For example, saying that a reference signal has increased 50 dB is much easier than saying that the output has increased 100,000 times.

The basis of the decibel measuring system is the amount of increase or decrease from a reference level. Whether the input power is increased from 1 watt to 100 watts or from 1,000 watts to 100,000 watts, the amount of increase, or gain, is still 100 times or 20 dB. Examine table 1-2 again, taking particular note of the power ratios for source levels 3 dB and 6 dB. As the table illustrates, an increase of 3 dB represents a doubling of power. The reverse is also true. If a signal decreases by 3 dB, half of the power is lost. For example, a 1,000-watt signal decreased by 3 dB will equal 500 watts, while a 1,000-watt signal increased by 3 dB will equal 2,000 watts.

Table 1-2.—Decibel Power Ratios

Source Level (dB)		Power Ratio
1	=	1.3
3	=	2.0
5	=	3.2
6	=	4.0
7	=	5.0
10	=	$10 = 10^1$
20	=	$100 = 10^2$
30	=	$1{,}000 = 10^3$
40	=	$10{,}000 = 10^4$
50	=	$100{,}000 = 10^5$
60	=	$1{,}000{,}000 = 10^6$
70	=	$10{,}000{,}000 = 10^7$
100	=	10^{10}
110	=	10^{11}
140	=	10^{14}

When you speak of the dB level of a signal, you are actually speaking of the logarithmic comparison between the input and output signals. The input signal is normally used as the reference signal. In some instances, a standard reference signal must be used in place of the input signal. The most widely used reference level is a 1-milliwatt signal (600-ohm load). When the 1-milliwatt reference is used, the standard decibel abbreviation of dB is changed to **dBm;** dBms are used as an indication of power, while dBs are used to indicate the ratio between the input and output.

A signal level of +3 dBm is 3 dB above 1 milliwatt, and a signal level of –3 dBm is 3 dB below 1 milliwatt. Whether you are using dB or dBm, a plus sign (+) or no sign indicates that the output level is

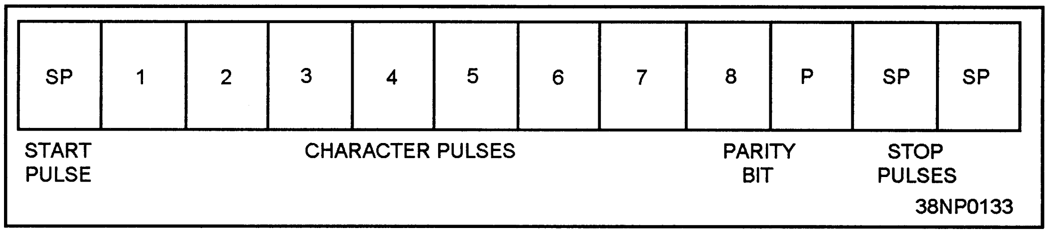

Figure 1-2.—Asynchronous character code.

greater than the reference (power gain), while a minus sign (–) indicates that the power level is less than the reference (power loss). The value 0 dBm indicates that the output power is equal to the 1-milliwatt reference. It is also used to express a definite amount of power (1 milliwatt). The value 0 dBm equates to 1 milliwatt.

DIGITAL DATA COMMUNICATIONS TECHNIQUES

Data signals transmitted over communications channels need to follow specific protocols to ensure they are synchronized. In normal I/O data exchanges, this process is accomplished by the system of requests and acknowledges. In addition, the data signals have to be properly formatted for the receiving computer to decode them properly.

ASYNCHRONOUS AND SYNCHRONOUS COMMUNICATIONS

Two major data-formatting methods are used to make sure the transmitting computer and the receiving computer(s) are synchronized: asynchronous (character framed) and synchronous (message framed). Both methods are used to identify intelligence transmitted in the form of serial bit streams.

Asynchronous Transmission

Asynchronous transmission of data is commonly found in landline communications systems and some forms of teletype communications. Generally, asynchronous, or character-framed, transmission is used to transmit seven- or eight-bit data, usually in ASCII character format. Each character has a specific start and end sequence—usually one start bit and one or two end (stop) bits. Figure 1-2 illustrates the transmission format of an asynchronous data stream. A parity bit (even or odd) maybe included to ensure the accuracy of the transmitted data. Asynchronous characters may be transmitted one at a time or as a string of characters; however, each character transmitted will have start and end bits. When data signals are transmitted in this format, synchronization occurs on a character-by-character basis between the transmitting and receiving devices and provides some allowance for timing inaccuracies. Any inaccuracy in timing is corrected with the arrival of the next character.

Synchronous Transmission

Most tactical digital information links communicate using synchronous messages. Synchronous transmission is a more sophisticated method of data transmission. It sends data in long uninterrupted streams, with a predefine start and stop sequence. The start sequence is generally referred to

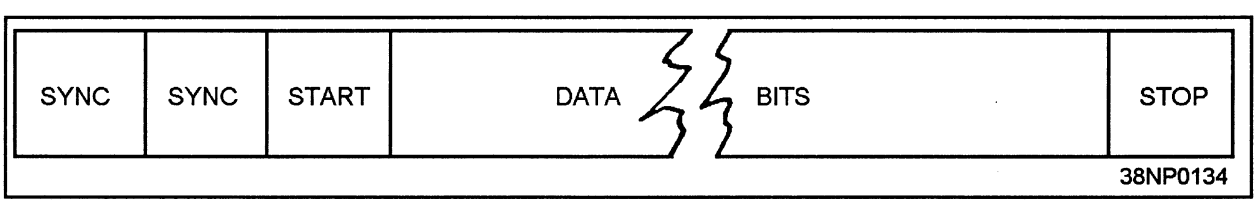

Figure 1-3.—Synchronous message format.

as the preamble. The principal function of the preamble is to alert the receiver of incoming data and provide a reference to synchronize the receiver with the transmitted signal. Following the preamble is a start code that informs the receiving equipment of the beginning of the message data. The basic format of the synchronous data message is shown in figure 1-3. The incoming bit stream is then used to synchronize the receiver or demodulator timing. A stop code follows the message data to indicate the end of transmission.

MODULATION/DEMODULATION

Modulation modifies a signal so it can carry data over the communications channel. The demodulator removes the data from the carrier. For most data communications applications, the carrier is a continuous sinusoidal waveform (sine wave). The frequency of the carrier varies, depending on the application. Landline transmission generally uses the audio-frequency bandwidth signals (300 to 3,000 Hz). Radio channels use audio-frequency tones as data carriers modulated to a radio-frequency signal, or they modulate the radio-frequency signal itself to convey data.

The three basic modes of modulation are **amplitude modulation, frequency modulation,** and **phase modulation.** Each of these modes modifies the carrier signal in some manner to convey data.

Amplitude Modulation

When amplitude modulation is used for digital transmissions, the amplitude of the carrier signal represents the two discrete data states (1 or 0). The signal represents a logic 1 when the amplitude (peak-to-peak), at the same frequency, is greater at a different time, as shown in figure 1-4. The decrease in signal amplitude, below a predetermined threshold, indicates a change from a logic 1 to a logic 0.

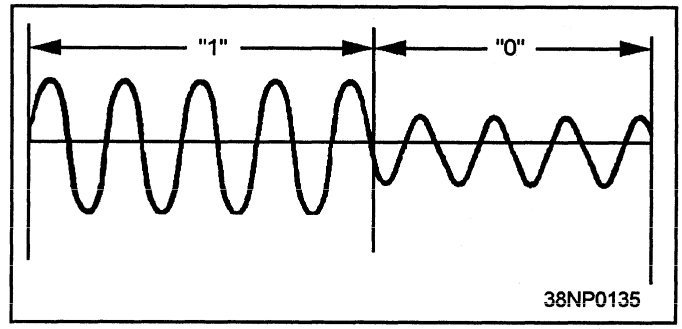

Figure 1-4.—Amplitude modulation.

Frequency Modulation

The frequency of the carrier signal or audio tones modulated to the carrier signal can be modified to indicate the two discrete states. As shown in figure 1-5, a selected frequency can be used to indicate the 1 state of a bit, and another selected frequency can be used to indicate the 0 state. The change in frequency, or frequency shift, indicates the same relationship as the change in amplitude did in amplitude modulation.

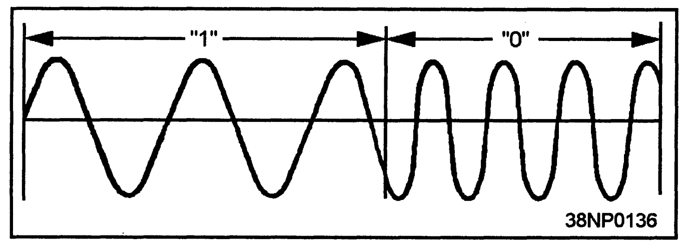

Figure 1-5.—Frequency modulation.

Shifting the frequency of the carrier signal is called **frequency-shift keying** (FSK) or **binary frequency-shift keying** (BFSK). FSK usually involves shifts to frequencies above or below a selected center frequency. Transmission of the frequency above the center frequency indicates a binary 1; the frequency below the center frequency indicates a binary 0. The center frequency is not transmitted. FSK is used in systems such as link 4A.

Another method of using frequency shifts involves audio-frequency tones. Two discrete audio tones may be modulated to a constant frequency carrier signal. One of the tones is used to indicate a mark, or binary 1, the other a space, or binary 0. This method of frequency modulation is called **audio-frequency tone shift** (AFTS).

Phase Modulation

Phase modulation is a more complex mode of modulation. It is based on the relationship of the

360-degree carrier sine wave to the baseline of the sine wave. The carrier signal starts on the baseline, as illustrated in figure 1-6, and continues to form a curve called the sine wave. When the sine wave reaches its maximum positive amplitude, it is at the 90-degree point. When it returns to the baseline, it is at 180 degrees. When it reaches its maximum negative amplitude, it is at 270 degrees; and when it returns to the baseline, it is at 360 degrees or the 0-degree point for the start of the next cycle. This process occurs over a period, with the number of full cycles per second (Hz) being the frequency of the signal. A full cycle is the transition from the 0-degree point to the 360-degree point.

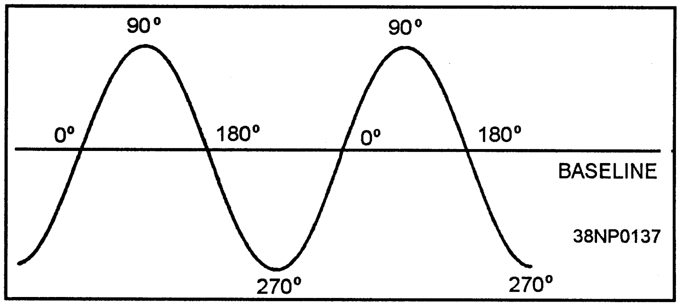

Figure 1-6.—Carrier sine wave,

For a particular frequency this process continues without interruption. Phase modulation involves interrupting the cycle at one or more degree points and instantaneously changing the direction or amplitude of the sine wave. Figure 1-7 shows how a 180-degree phase shift is used to indicate two discrete states. The third cycle of the carrier is interrupted at the 180-degree point. Instead of continuing in the negative direction, the sine starts at the 0-degree point again. The resultant signal has the same frequency and amplitude as the original signal but is 180 degrees out of phase. This phase shift can be directly related to a digital input at a modulator in which one

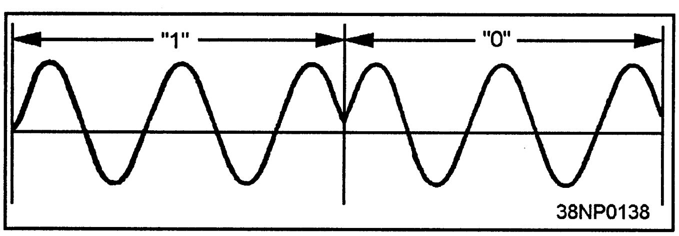

Figure 1-7.—Phase modulation.

particular phase represents the 0 bit and the other phase represents the 1 bit.

Multibit Modulation

While the 180-degree phase shift can be used to indicate two discrete states, many points on the sine wave can be defined to represent different bit configurations. Individual phase changes of 0 degrees, 90 degrees, 180 degrees, and 270 degrees from a reference phase can each represent two separate data bits. For example, a 0-degree phase shift or no phase shift could indicate a binary 00; a 90-degree phase shift, a binary 01; a 180-degree phase shift, a binary 10; and a 270-degree phase shift, a binary 11. This type of modulation is known as a multibit, or quadrature (four-state) phase-shift modulation, as shown in figure 1-8. Keep in mind that only one continuous frequency and amplitude signal is being phase-modulated to transmit two bits of data for each phase shift.

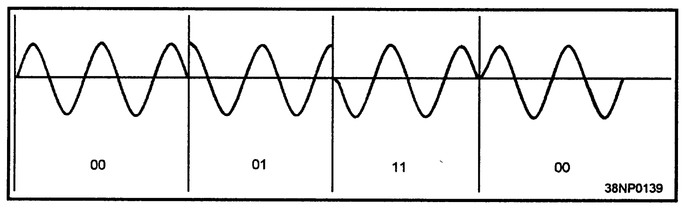

Figure 1-8.—Multibit phase modulation.

A modification of the quadrature phase-shift modulation, called differential quadrature phase-shift keying, uses the difference between a phase-shifted signal and its preceding sine wave to represent data. When a phase shift is detected, the current signal is compared with the previously transmitted phase signal. The difference between the two signals is computed to determine the amount of phase shift. The previously transmitted signal is used as the reference phase for demodulating the data bits. Two binary digits are represented by phase changes of -45, -135, -225, and -315 degrees. The -45 degree shift indicates a binary 11; the -135 degree shift, a binary 01; the -225 degree shift, a binary 00; and the -316 degree shift, a binary 10.

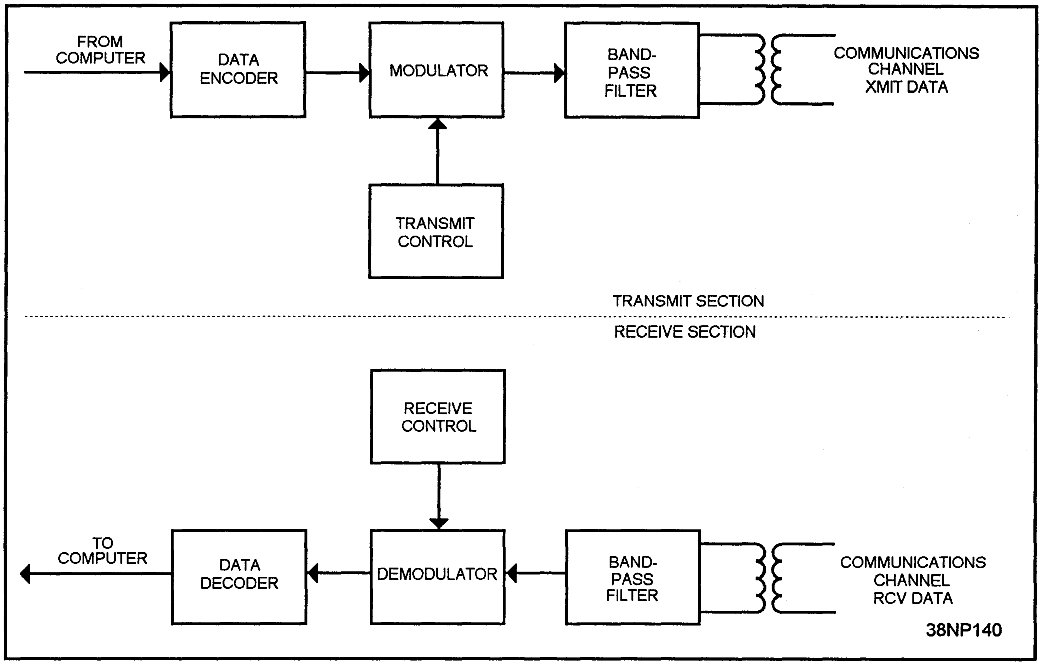

Figure 1-9.—Full-duplex modem.

MODEMS

Modems come in a variety of configurations. Their design depends on a number of factors, including the following:

- Asynchronous or synchronous data transmissions
- Simplex, half-duplex, or full-duplex communications
- Type of communications channel
- Type of modulation/demodulation used

Modems may be stand-alone devices with their own power supplies and indicators. They may also be integrated into the design of larger equipments in which the modulations or demodulations are only one of the functions performed by the device.

A functional block diagram of a modem is shown in figure 1-9. A full-duplex modem consists of two sections: the **transmitter** and the **receiver sections.** These two sections are functionally separate from each other.

Transmitter Section

The transmitter section consists of a data encoder, the modulator, the band-pass filter, and the transmit control logic. The data encoder takes the digital data signal to be transmitted, and when necessary, converts it into the bit pattern acceptable to the modulator circuit. The modulator converts the data into the carrier signal. The most popular forms of modulation are frequency-shift keying (FSK), phase-shift keying (PSK), and quadrature phase-shift keying. After the data signals are modulated, they are fed to the band-pass filter circuitry. The band-pass filter then allows only the desired frequency to pass through the communications channel. The transmit control logic provides the timing signals necessary for the transmission of data to take place.

Receiver Section

The receiver section consists of a band-pass filter, a demodulator, a data decoder, and the receiver control circuit. The band-pass filter allows only the desired carrier signal to be received from the communications channel. The demodulator removes the data from the carrier signal and feeds the data to

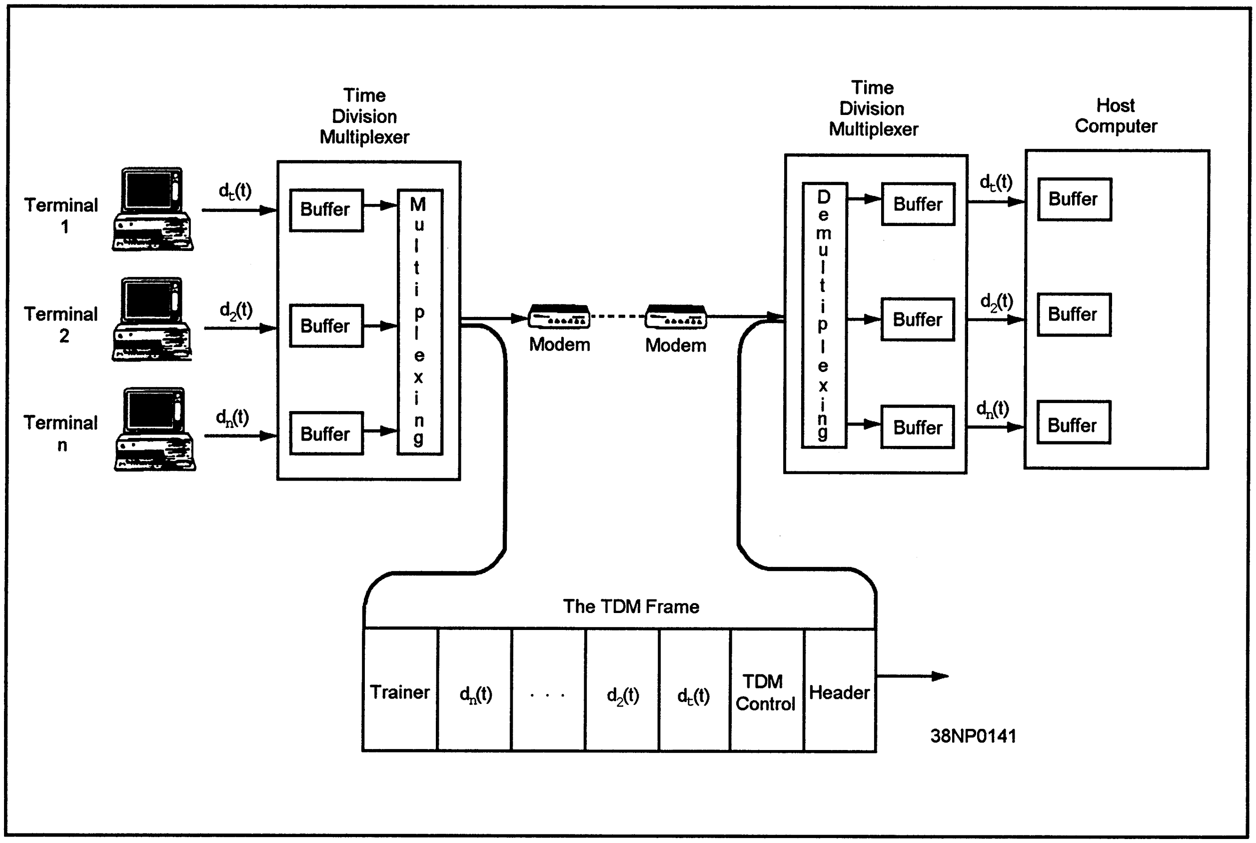

Figure 1-10.—A time-division multiplexer (TDM) system.

the decoder. The decoder reassembles the data into a form compatible with the receiving system. In the receiver section, the incoming signal is often fed to the receiver timing logic to control the receiver timing circuitry.

MULTIPLEXING

One requirement of a data communications system is for it to transmit as many intelligent signals as possible in a fixed period using a single-communications channel. The rate of data transmission is measured in the number of bits per second (bps) transmitted. The bps rate is often confused with the baud rate. Baud refers to the rate at which a modulated signal between two devices changes in 1 second. For example, if the signal between two modems changes frequency or phase at a rate of 2,400 times per second, the baud is 2,400. If you are using a modulation method in which a single modulation change carries one bit, the 2,400 baud is also 2,400 bits per second. Using more sophisticated modulation methods, several bits of information can be designated in a single modulation change. If two bits of data are transmitted with each modulation change, the data transfer rate is 4,800 bits per second at 2,400 baud.

The data signals being transmitted are normally multiplexed to increase the transmission rate of data over the communications channel or to increase the efficiency of the channel by allowing multiple users of the same channel. The two methods commonly used to multiplex communications channels are **time-division multiplexing** and **frequency-division multiplexing.**

Time-Division Multiplexing

Time-division multiplexing (TDM) grants each user full channel capacity, but assigns time slots to each user. Each user is connected to a time-division multiplexer. Data signals from the user are fed to the time-division multiplexer buffer, and the time slots are rotated among the users and scanned for data. Figure 1-10 illustrates the typical construction of a time-division multiplexer system. The data from each user can be in the form of bits, bytes, or blocks. The data signals from all users are compiled into frames for transmission on a single, high-speed communications channel.

Transmit and receive frames are used for half-duplex communications. Transmit frames are sent and a receive time slot is enabled for return information. In this manner, a single carrier frequency and modem may be used to transmit and receive information at a fairly high rate of speed.

Since time slots are preset and assigned, if a user has no data to transmit, the time slot is wasted. Advantages of a TDM system include the following: its ability to handle devices with varying speeds, its effectiveness when used with devices that transmit data almost continuously, and its simple implementation.

Frequency-Division Multiplexing

Frequency-division multiplexing (FDM) divides a band of frequencies into several distinct channels or tones. Each tone carries a portion of the data being transmitted. FDM devices can be complex because a separate modulator/demodulator circuit is required for each tone used. The composite tones are then modulated to a single carrier frequency for radio transmission.

FDM allows for the parallel transmission of data over a single communications channel. For example, the Link-11 communications system uses 15 audio tones to transmit 30 bits of parallel data. Each tone transmits two bits of differential quadrature phase-shift keyed data.

SUMMARY—FUNDAMENTALS OF DATA COMMUNICATIONS

This chapter introduced you to the building blocks of a data communications system. The following information summarizes the important points you should have learned.

COMMUNICATIONS SYSTEMS— Digital data devices that exchange data over distances are known as communications systems. A basic communications system consists of the following three components: a transmitter, a receiver, and a communications channel. The transmitter converts digital data into a form (digital or analog) useable by the communications channel. The receiver accepts data from the communications channel and converts the data back to its pure digital form. Communications systems that can transmit and receive data are known as duplex systems, while communications systems that are limited to transmit only or receive only are simplex systems. Duplex systems that transmit data, pause, and then receive data are half-duplex systems. Full-duplex systems can transmit and receive data simultaneously.

COMMUNICATION CHANNELS— Several types of communications channels are in use today. The most common are landlines and radio communications. Landlines are physical cables that connect computers; they are common in local area networks. Radio communications use the radio-frequency bands to exchange information. The most common bands used in the Navy are the HF and UHF bands.

DECIBEL MEASUREMENT SYSTEM— The decibel measurement system is used to measure the gain or loss of amplifiers, antennas, communications lines, and other types of communications equipment. A gain of +3 decibels (dB) indicates that the output power of the circuit, compared to the input power, has doubled. Each +3 dB gain indicates a doubling of power. For example, a signal that has a gain of 6 dB is twice as strong as a signal that has a gain of 3 dB.

ASYNCHRONOUS TRANSMISSION— Asynchronous transmission refers to data sent without the use of timing pulses. Data signals are sent a byte at a time, with start, stop, and parity bits added to each byte.

SYNCHRONOUS TRANSMISSION— Synchronous transmission refers to the sending of long, uninterrupted streams of data with a predefined start and stop sequence.

MODULATION/DEMODULATION— Modulation is the modifying of a signal to carry intelligent data over the communications channel. Several types of modulation are available, depending on the system requirement and equipment. The most frequently used types of modulation are amplitude modulation, frequency modulation, and phase modulation. Demodulation is the act of returning modulated data signals to their original form.

AMPLITUDE MODULATION— Amplitude modulation refers to modifying the amplitude of a sine wave to store data.

FREQUENCY MODULATION— Frequency modulation refers to changing the frequency of a signal to indicate a logic 1 or a logic 0. One frequency indicates a logic 1, and the other frequency indicates a logic 0.

PHASE MODULATION— Phase modulation is more complex than amplitude modulation or frequency modulation. Phase modulation uses a signal frequency sine wave and performs phase shifts of the sine wave to store data. A modification of phase modulation involves the use of several discrete phase shifts to indicate the state of two or more data bits.

MODEMS— A modem is a device that MOdulates and Demodulates data in a digital communications system. Modems are available in a variety of types, with various speeds and capabilities. A modem consists of two functionally separate areas—the transmitter section and the receiver section. The transmitter section prepares, or modulates, the data for transmission. The receiver section demodulates, or returns, incoming data to its original form.

MULTIPLEXING— Multiplexing refers to processes used in digital communications systems to make the most efficient use of system time. Multiplexing can involve time-sharing of the communications channel by several users or assigning several frequencies for the parallel transmission of data.